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ANALYSIS OF PHOTOGRAPHIC COVERAGE OF THE SATURN SA-2 WATER EXPERIMENT ON APRIL 25, 1962

By

H. D. Edwards

L. C. Young

C. G. Justus

TECHNICAL REPORT NO. 1

PROJECT A-637

Contract No. NAS8-5064

Prepared for
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama

September 1962

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

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ABSTRACT

This report describes the results obtained from photographic studies of a release of 86,000 kg of water from the Saturn SA-2 space vehicle at an altitude of approximately 105 km. The vehicle was launched at 0900:34 EST on April 25, 1962 and the water was released 162.583 $\pm$ .006 sec after vehicle launch.

Photographic coverage was provided by the Atlantic Missile Range. The objective of the Georgia Tech effort has been to analyze the photographic records which were supplied by Marshall Space Flight Center scientists. The results of these analyses are presented in this report.

A brief description is given of the vehicle-borne and ground-based instrumentation.

Experimental results have been given on the following parameters:

(1) Rocket Position at Time of Water Release

(2) Rocket Angular Motion Following Release

(3) Cloud Composition

(4) Spectral Characteristics of the Cloud

(5) Location of Water Cloud in Space

(6) Position of High Intensity Line

(7) Cloud Growth

(8) Intensity of Cloud

Positive results on several of the above parameters were not possible due to limitations of the photographic data.

Several recommendations have been made, which if possible to carry out, would improve the photographic records. These are:

(1) Shorter focal length lenses should be used to achieve a field of view of 20° to 30° in both horizontal and vertical directions.

(2) Azimuth-elevation of star background data should be provided for each frame of film.

(3) Spectral data should be obtained by spectrographs or filters.

(4) Black and white film should be used instead of color.

(5) Sensitometric strips should be processed with the film and H-D curves established.

(6) Separate destruct systems should be provided for the water and fuel-LOX so the water is not released at the same time as other constituents.

INTRODUCTION

The technique of releasing trace atoms and molecules into the upper atmosphere to study winds, diffusion, composition, and other interactions with the ambient is well known and has been discussed extensively in the literature.

The release discussed in this report consisted of 86,000 kg of water carried to an altitude of approximately 105 km by means of the Saturn SA-2 Missile. At this altitude the water was released by the blast from primacord wrapped around the water-filled second and third stages.

Photographic coverage was provided by the Atlantic Missile Range and other interested organizations having appropriate instrumentation.

The objective of Georgia Tech personnel has been to analyze the photographic records which were supplied us by Marshall Space Flight Center scientists and to assist in developing pilot techniques which will aid in future flights.

INSTRUMENTATION

Rocket Borne   From the viewpoint of the water cloud experiment the only "instruments" on the rocket were two tanks of water with a total weight of 86,000 kg and sufficient primacord to open the tanks and spill the water into the atmosphere. Details of the rocket and associated instrumentation are given elsewhere [Astronautics February 1962, Johnson et.al. 1962]. In addition to the water, residual fuel and liquid oxygen left in the tanks after burnout were released at the same time as the water. The liquid oxygen was contained in a central tank 2.67 m in diameter and in four other tanks of 1.78 m diameter clustered about the center tank. The fuel was carried in four additional tanks of 1.78 m diameter spaced alternately with the oxygen tanks. All tanks were approximately 15.24 m long.

The dummy second stage of the missile carried about 44,000 kg of water contained in an inner tank 2.67 m in diameter and 8.31 m long located centrally within the dummy stage, 5.59 m in diameter.

The dummy third stage carried about 42,000 kg of water in a tank 3.05 m in diameter and 7.19 m long.

The release of the water was accomplished through the vehicle command destruct system. This system employed strings of primacord to cut each fuel and oxidizer tank longitudinally. Additional primacord was spliced into the system to cut the two water tanks. In each case, the primacord ran through a conduit within the tank, but adjacent to the tank wall. The tank composing the dummy third stage could be very effectively ruptured by the explosives. The dummy second stage presented a greater difficulty since its walls were 1/4-inch steel. Here it was practical to produce four 56- by 80-inch ports in the outer wall. The inner tank containing the water would be very effectively ruptured by its charge. The entire pyrotechnic train was initiated through a radio link on command from the ground. This command was given, as planned, when tracking indicated the vehicle had reached 105 km altitude.

Ground Based A wide variety of optical instrumentation was available for recording phenomena subsequent to the release of water. An itemized listing of these instruments is given in reference 2 and will not be repeated here. In the following table a list is given of the film which we studied together with some characteristics of the cameras.

Film - Camera Data

Item No.	Camera Type	Site Location	Film Type	Frame Rate	Focal Length	f No.	Shutter Opening
1.2-64U	70mm IGOR	False Cape	ER(1)	30	180"	10	15°
1.2-65U	70mm IGOR	Williams Point	LSB(2)	10	360"	5	15°
1.2-68U	70mm ROTI	Melbourne Beach	ER	20	400"	16.7	90°
1.2-69U	70mm ROTI	Vero Beach	LSB	10	100"	4.3	5°
1.2-67U	35mm Mit	Patrick	ER	94(3)	360"	20	75°
1.2-71U	35mm Mit	U242L90	LSB	24	20"		
1.2-74U	35mm Mit	Vero Beach	LSB	24	20"		
1.2-130U	35mm		Color				
3.2-2U	35mm Mit	Grand Bah. Gold Rk. Cr.	LSB	24	40"		
1.2-103U	16mm		Color				
1.2-104U	16mm		B/W				

(1) Ektachrome Reversal

(2) Linograph Shell Burst

(3) Calculations show frame rate of 94 per sec instead of 48

The following table gives station coordinates for several of the camera sites.

STATION COORDINATES

Station	Item No.	Latitude			Longitude			Elevation
		Deg	Min	Sec	Deg	Min	Sec	Feet
False Cape (IGOR)	1.2-64U	28	35	6.402	80	34	43	41
Williams Point (IGOR)	1.2-65U	28	26	58	80	45	45	57
Patrick (IGOR)	1.2-67U	28	13	36	80	35	59	38
Melbourne Beach (ROTI)	1.2-68U	28	02	57	80	32	55	39
Vero Beach (ROTI)	1.2-69U	27	40	37	80	21	48	12
U242L90	1.2-71U	28	31	28.3	80	34	35	
Grand Bahama Island								
West End		26	39	15	78	55	59	5.6
Gold Rock Creek		26	36	14	78	22	19	25
Pelican Point		26	38	33	78	06	48	22.3

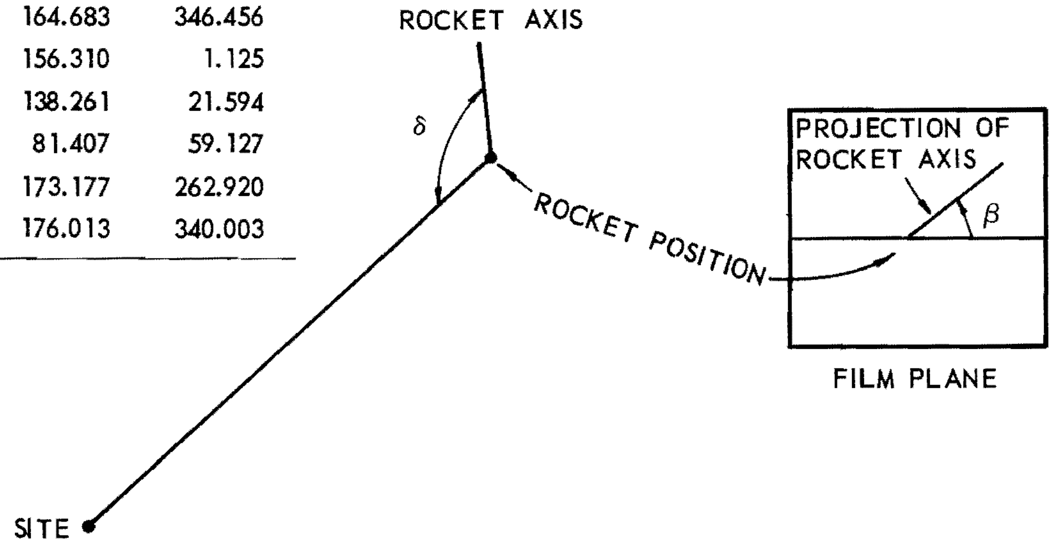
EXPERIMENTAL RESULTS

Rocket Position at Time of Water Release From extrapolation of cloud growth curves (discussed in a later section), the time of cloud release was 162.583 ± .006 sec after vehicle launch. The altitude of release was 105.265 km at a latitude of 28.39413° and a longitude of 79.74769°. Burnout of vehicle engines occurred 45 sec prior to release.

The apparent orientation of the rocket longitudinal axis at the time of water-liquid oxygen-fuel release has been calculated for each observing site and the results are presented in Figure 1. At the instant the water and residual propellants were released, the vehicle axis made an angle of 44.3° with the vertical and had an azimuth of 99.1° from north [Johnson et.al. 1962].

The apparent orientation of rocket fins III and IV at the time of release are given in Figure 2. The initial location of fin III at time of release was given by Fields (private communication) to be 4.5° from the vertical plane which

SITE	δ	β
1	172.711	236.731
2	164.683	346.456
3	156.310	1.125
4	138.261	21.594
5	81.407	59.127
6	173.177	262.920
7	176.013	340.003



β VERSUS SITE NUMBER

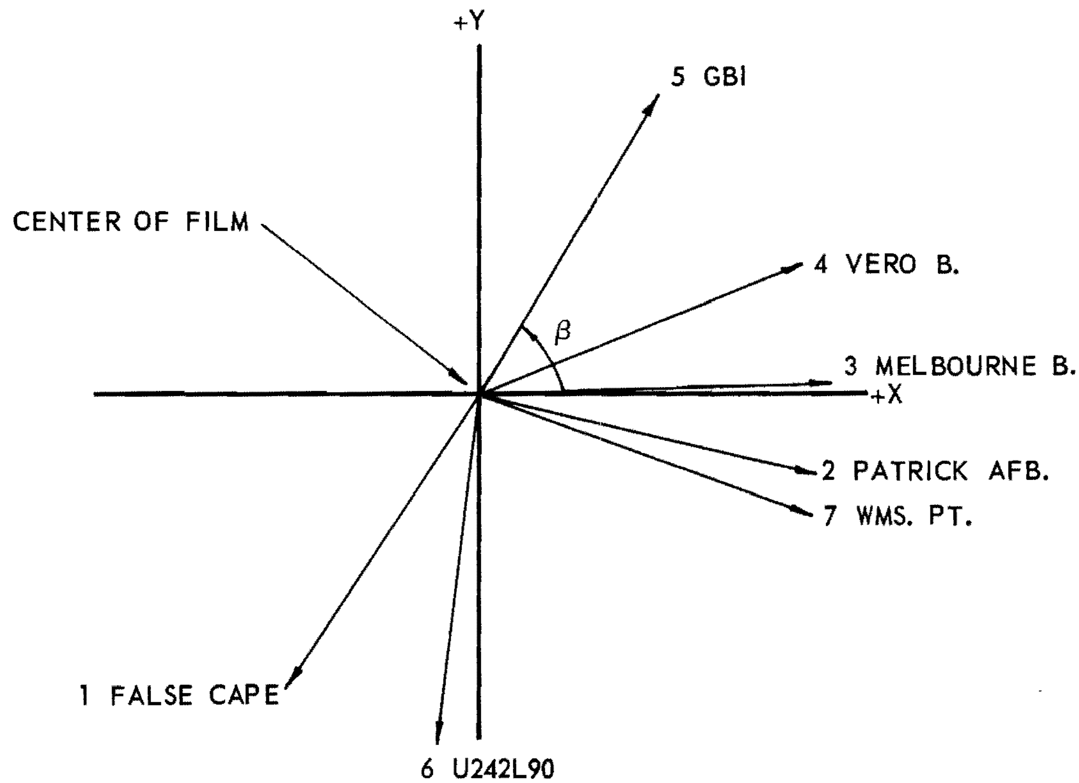
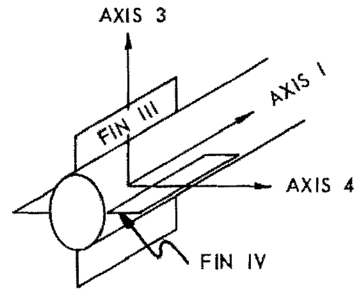


Figure 1. Apparent Orientation of Rocket Longitudinal Axis at the Time of Release.

AXIS 3		
SITE	δ	β
1	96.205	81.377
2	96.015	100.851
3	97.719	110.248
4	103.046	127.329
5	133.334	141.527
6	96.394	84.593
7	90.893	89.303

AXIS 4		
SITE	δ	β
1	93.066	351.110
2	76.209	12.401
3	67.956	23.467
4	51.433	48.064
5	44.584	157.882
6	90.248	354.631
7	86.283	359.426



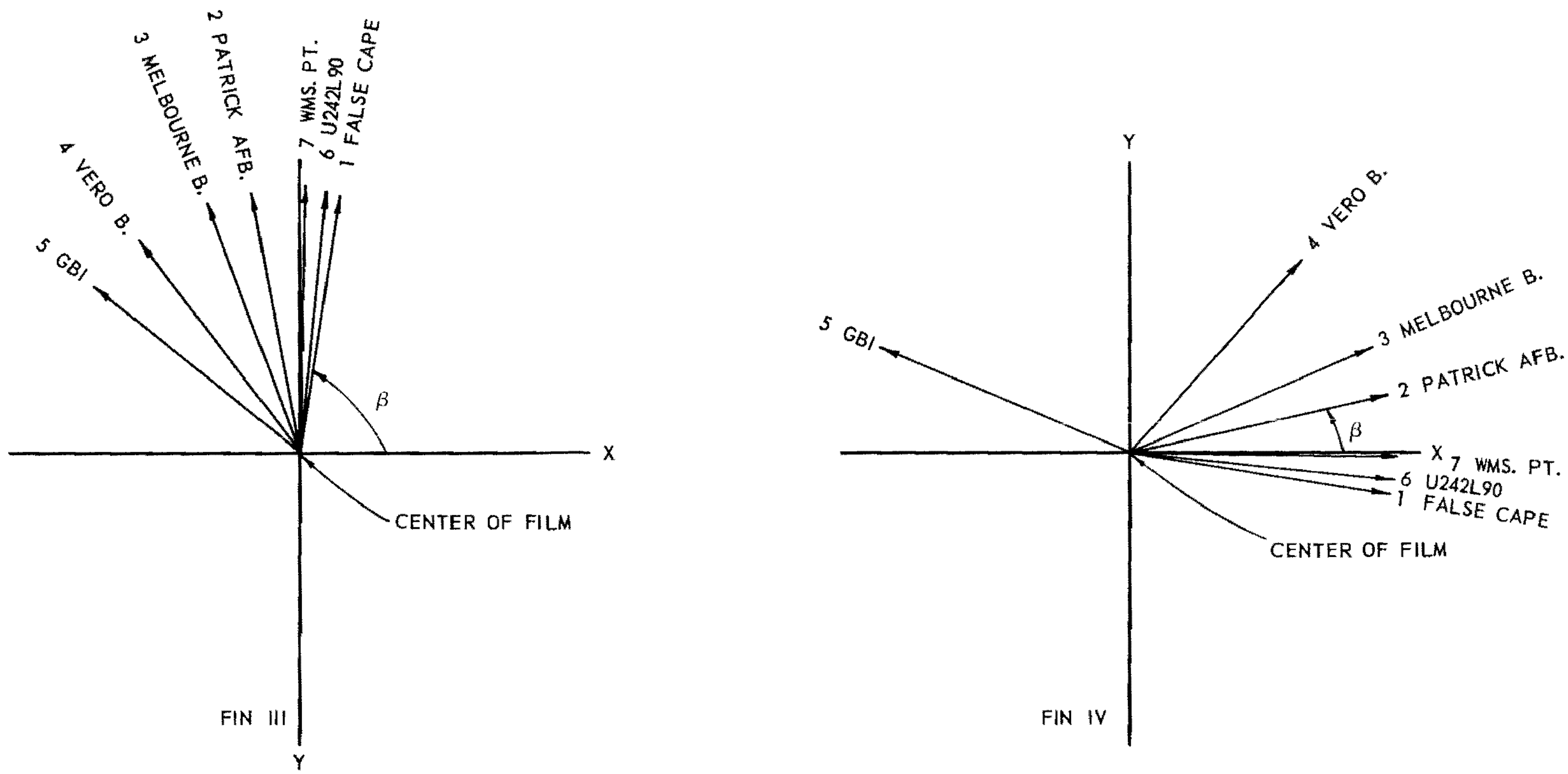


Figure 2. Apparent Orientation of Rocket Fins III and IV on Film Plane.

includes the longitudinal axis.

Azimuth and elevation of the axes established for fins III and IV are 272.8° and 44.1° for fin III and 185.9° and -3.1° for fin IV. Azimuth is measured in degrees East of North and elevation in degrees above or below the horizontal. Sketches of these two axes are shown in Figure 2.

For the above two calculations the rocket has been assumed to be at the center of the film. In practice this was very nearly so, since the camera operators were tracking and in general kept the rocket in the center of the frame.

In Figure 3 the projection of the translational velocity vector in the film plane is presented.

Rocket Angular Motion Following Release The angular momentum imparted to the missile by escaping fuel and liquid oxygen is depicted in Figure 4 and given by the following relation.

$$L_c = \Sigma\, mfvr = [m_{o_2} f_{o_2} v_{o_2} + m_{RP-1} f_{RP-1} v_{RP-1}] \times r \sin \alpha$$

where: f is the fraction vaporized

c denotes constants

$v_{o_2} \sin \alpha$ is directed clockwise

$v_{RP-1} \sin \alpha$ is directed counterclockwise

$L_c = [7.500 \times .390 \times 231 - 10{,}000 \times .235 \times 215] \times 3.04 \times .308$

$= 160{,}000 \text{ lbs m}^2/\text{sec} = 73{,}000 \text{ kg m}^2/\text{sec}.$

In both this and the subsequent balancing equation, the weight of the fuel and missile are treated as mass, for simplicity.

The angular momentum imparted to the missile by the booster destruct system has also been determined.

Each fuel tank had 50 ft of primacord fastened longitudinally along its axis with a concentration of 400 grains/ft or a total of 1.3 kg/tank.

SITE	δ	β
1	165.516	256.357
2	158.847	328.713
3	151.188	347.157
4	133.512	12.339
5	74.771	54.568
6	165.298	270.715
7	169.346	300.351

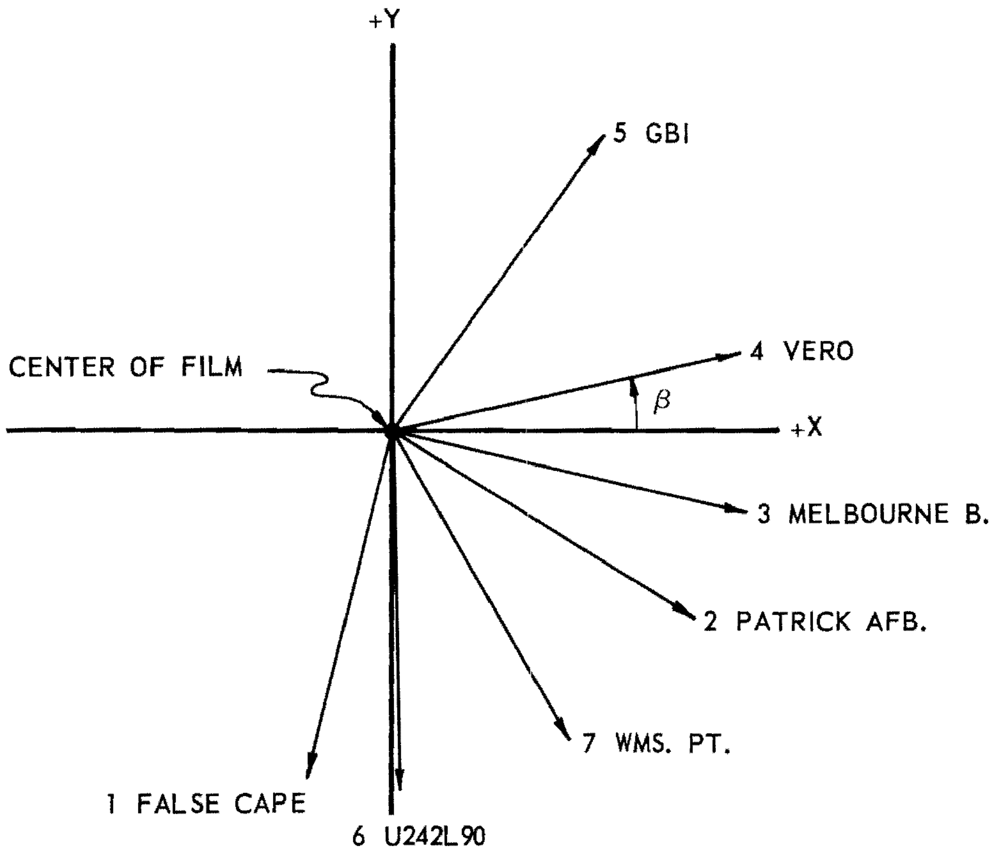


Figure 3. Projection of the Rocket Translational Velocity Vector in the Film Plane.

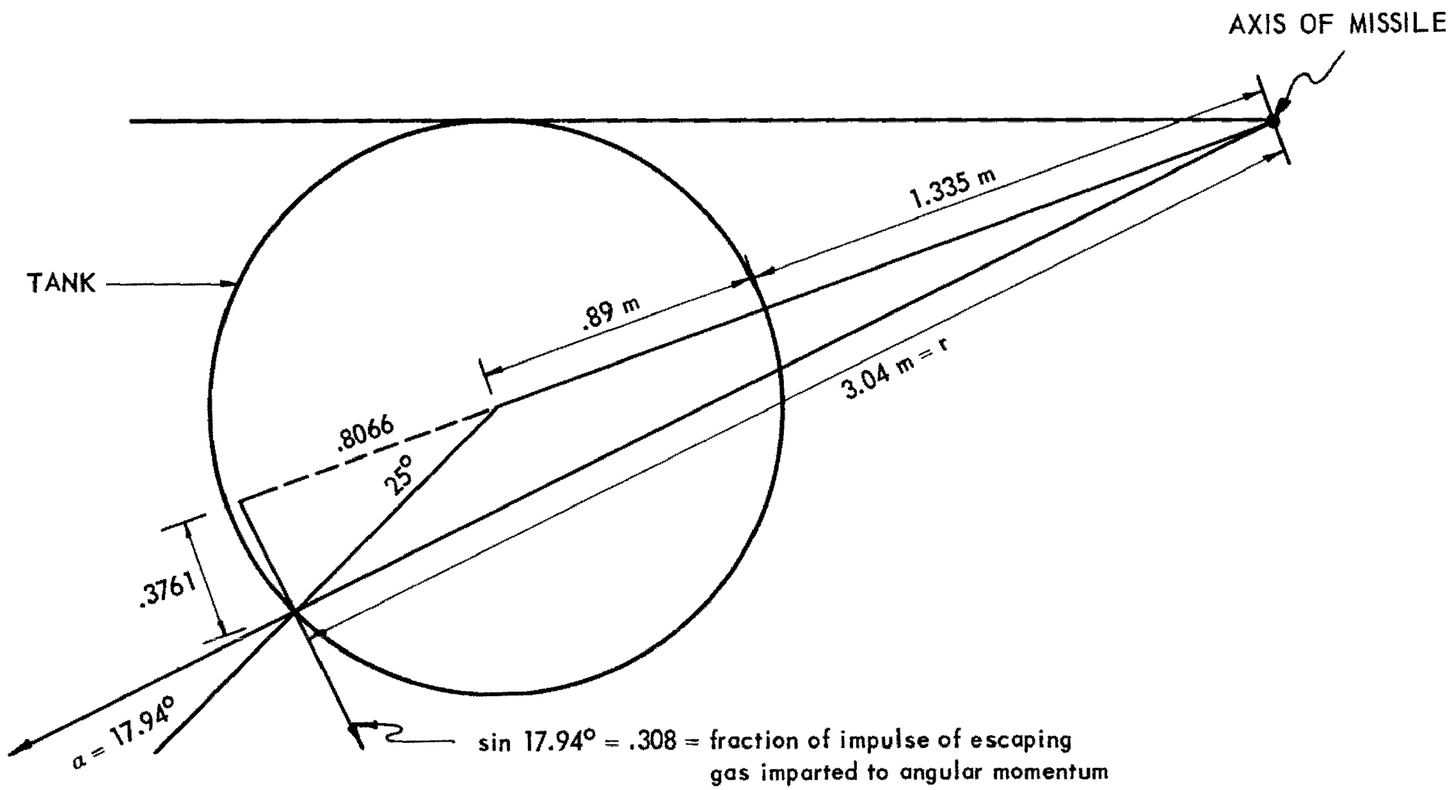


Figure 4. Geometry of Angular Momentum Imparted to the Missile by Escaping Fuel and Liquid Oxygen.

The liquid oxygen tanks had the same arrangement except that the primacord was truncated at 0.6 of the length.

Velocity of the explosive gases was assumed to be approximately 4000 m/sec. The radius and direction of the exploding gases were assumed to be the same as that for the escaping fuel and liquid oxygen as shown in Figure 4.

Hence, the net angular momentum imparted to the missile by the exploding gases is:

$$L = m\,v\,r$$

$$L_e = [.4 \times 1.3 \times 4] \times 4{,}000 \times 3.04 \times .308$$

$$= 8{,}000 \text{ kg m}^2/\text{sec}.$$

Observations made from the Melbourne Beach film made possible a rough estimation of the angular velocity of the missile as a function of time after release. These data are presented in Figure 5 and show an angular velocity of about 1 rad/sec at a time 10 sec after release. This velocity decreased to about 0.75 rad/sec at a time 40 sec after release.

A rough calculation has been made of the angular velocity expected from a rigid solid cylinder such as the tanks filled with water.

The angular momentum of a cylinder is given by

$$L = \frac{MR^2\omega}{2}$$

where M = mass of the cylinder

R = radius of the cylinder

ω = angular velocity

for the 2nd stage water

$$L_1 = \frac{44{,}000 \times 1.335^2}{2}\,\omega = 39{,}200\,\omega$$

for the 3rd stage water

$$L_2 = \frac{42{,}000 \times 1.525^2}{2}\,\omega = 48{,}800\,\omega$$

for the empty missile (1st + 2nd + 3rd stages) if we assume 30,000 kg at 1.8 m radius of gyration

$$L_M = 30{,}000 \times 1.8^2\,\omega = 97{,}200\,\omega$$

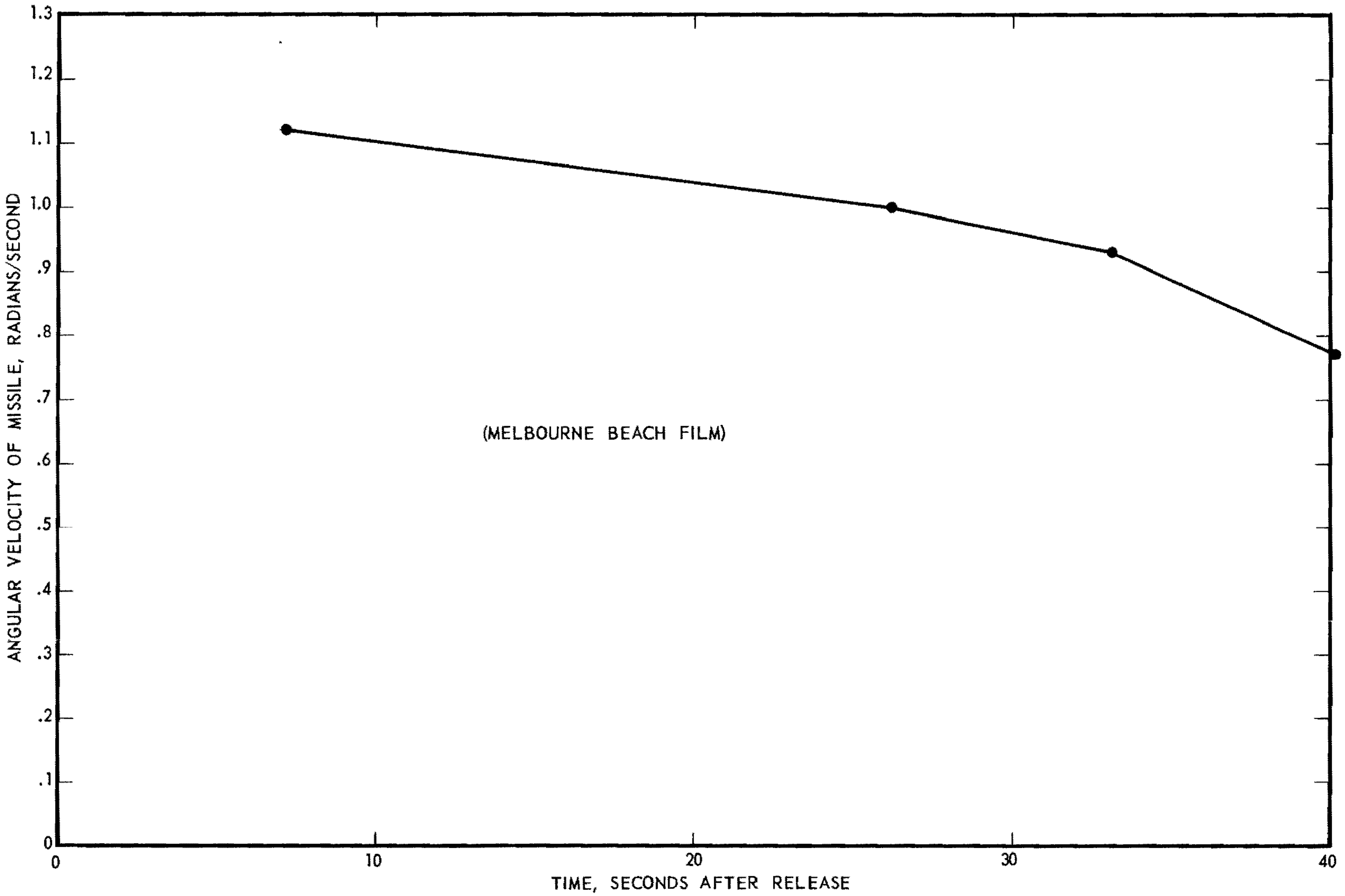


Figure 5. Angular Velocity of the Missile as a Function of Time.

Summing $L_M + L_1 + L_2 = 185{,}200\ \omega$.

If we assume that the water inside the tanks is not rotating

$$L_M = L_c + L_e$$

where L_c = angular momentum imparted to missile by escaping fuel and LOX as described in the previous section and L_e = net angular momentum imparted to the missile by the booster destruct system.

$$L_M = 97{,}200\ \omega = [73{,}000 + 8{,}000];\ \omega = 0.83\ \text{rad/sec}.$$

If we assume the water is rotating

$$L_T = 185{,}200\ \omega = 81{,}000;\ \omega = 0.44\ \text{rad/sec}.$$

Comparison of these calculations with the angular velocity of the missile (Figure 4) indicates that the water inside the tanks is turning initially with a lower angular velocity than the rotating tanks, as evidenced by the drop from 1.1 rad/sec at $t < 10$ sec to approximately 0.75 rad/sec at $t \approx 40$ sec.

Cloud Composition Whereas the primary objective was the release of water into the ambient, it was nevertheless necessary to include 3,400 kg of fuel and 4,600 kg of liquid oxygen since the method of release was by means of the missile destruct system and all tanks were ruptured at the same time.

Large solid or liquid particles of the released chemicals would not react with the ambient and would indeed follow the ballistic trajectory established by the vehicle. Our approach has been to determine that portion of the chemicals which would be reduced to the vapor state and would therefore at least have a chance to interact with the ambient atmosphere.

We would expect some evaporation of fuel to take place. For example, let us assume that we subject one gram each of cyclohexane (CYC), n-hexane (HEX), and toluene (TOL) to evaporation, removing the gas as it forms, and consecutively lower the temperature of the remaining liquid or solid. We will further assume that the latent heat of vaporization remains constant at 115 per cent of its value of the N.P. boiling point though properly this should be computed for the lower temperature.

Starting at 293° K and working toward 178° K; and using at 178° K 1.3 times the tabulated heat of vaporization for NTP, we get for this mixture*

CYC: $\frac{1-X}{M.W.} \times \int C_p \, dT = \frac{(1-X)}{84} \times [36.6 \times 11^\circ + 28.7 \times 60^\circ + 26.1 \times 20^\circ + 13 \times 24.^\circ]$

$= X_c \times L_v \times 1.15 = X_c \times \frac{7967 \times 1.15}{84}$, or $X_c = 0.245$ gm evaporated to bring remainder down to freezing point.

$Y_c \times L_v = (1 - X_c - Y_c) \, L_F$

$Y_c \times \frac{7967 \times 1.3}{84} = (1.0 - .245 - Y_c) \times \frac{627.8}{84}$, or $Y_c = .043$ gm evaporated to freeze remainder (.583 gm)

$F_c = X_c + Y_c = 0.288$

HEX; $(1-X) \, [44.8 \times 50^\circ + 41.8 \times 65^\circ] = X_H + 7387 \times 1.15$; $X_H = .369$

$Y_H \times 7387 \times 1.3 = (1 - .369 - Y_H) \, 3126$ $\quad Y_H = .155$

$F_H = X_H + Y_H = 0.524$

TOL; $(1-X) \, [36.0 \times 41^\circ + 33.6 \times 49^\circ + 32.2 \times 25^\circ] = X_T \times 9115 \times 1.15$; $X_T = .273$

$1.3 \times Y_T \times 9115 = (1 - .273 - Y_T) \, 1582$ $\quad Y_T = .086$

$F_T = X_T + Y_T = .359$

The average of these fractions vaporized is

$F = 1/3 \, [.288 + .524 + .359] = .390$

Hence, under ideal conditions we would expect about 0.4 of the fuel to be vaporized before freezing the remainder.

The average velocities of the component molecules of the kerosene may be assumed to be close to those of 220° K. For a molecule of molecular weight equal to 87, this is 231 m/sec.

Similarly, the evaporation of liquid oxygen from 90° K at 50.9 cal/gm would be sufficient to cool the remainder at a specific heat of approximately .40 cal/gm° K to 54° K and to freeze this remainder at 3.3 cal/gm.

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*The Air Force used these constituents to simulate kerosene in the July 20, 1960 release during the Firefly series.

This leads to

$$[36^{\circ} \times .40]\ (1 - X_o) = X_o \times 50.9 \times 1.15 \qquad X_o = .197$$

$$Y_o \times 1.3 \times 50.9 = (1 - .197 - Y_o) \times 3.3 \qquad Y_o = .038$$

$$F_o = X_o + Y_o = .235$$

Hence, as an upper limit only 0.235 or one-fourth of the total amount of liquid oxygen will be released with an average translational molecular velocity compatible with that at about 70° K, i.e. 215 m/sec.

Similarly we can expect about 16 per cent of the water to be vaporized provided all can be exposed to ambient conditions. This gives a possibility that about 10,000 kg of water was in the form of vapor. In spite of this large quantity of vapor the cloud would be most difficult to detect against a daylight sky, as the following computations will show.

We will assume that the H_2O vapor cloud is viewed in daylight through a conical path with pitch k. If the H_2O vapor scatters as much light as the intervening air, this will double the light received and increase the density of the film by the discernible amount of 0.3 in this region. Assuming that each H_2O molecule in the 10^4 kg of vapor scatters equally effectively as each O_2 or N_2 molecule,* then when the cloud is of such diameter that the cone contains the same number of molecules of air, the cloud will have produced the 0.3 density above background. This cone should therefore contain 1.6×10^4 kg of air.

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*Actually, the water molecule will scatter only 0.76 as much as the average of a molecule in air, as can be derived by considerations of refractive index and depolarization of anisotropic molecules outlined by Condon in Handbook of Physics.

The specific weight w of air in the lower atmosphere may be approximately related to height z in meters by $w = 1.225\ e^{-z/8000}\ kg/m^3$ (e.g. see graph of specific weight <u>vs</u> altitude on page 28, ARDC Standard Atmosphere 1959).

The weight of a vertical cone of air with its vertex at sea level and with a pitch (or tangent of half the vertex angle) of k is given by

$$W = \frac{\pi k^2}{3}\int_0^\infty w\ z^2\ dz = 1.2 \times 10^{12}\ k^2$$

For a cone whose axis has an elevation of $\alpha > 30^\circ$, the weight will be increased to $W' = W/\sin\alpha$

$$\text{or } W' = 1.2 \times 10^{12}\ k^2/\sin\alpha$$

For a nominal elevation of 45°, as the water release was viewed at the Cape, and for $W' = 1.6 \times 10^4$ kg, $W' = 1.6 \times 10^4 = 1.2 \times 10^{12}\ k^2/\sin 45^\circ$ and

$$k = 1.0 \times 10^{-4}.$$

At a nominal slant range r of 150,000 m, such a cone would be subtended by a cloud radius of

$$k \times r = 1.0 \times 10^{-4} \times 150{,}000 = 15\ m.$$

At an observed radial rate of growth of about 1,500 m/sec at the early cloud stages, 15 m would be reached in 0.01 sec.

Observations of the film taken at Williams Point indicate that the water was ejected over 60 sec, so that the vapor would never be sufficiently concentrated to be visible.

Hence, the cloud is composed of the vapors of water, fuel, and liquid oxygen and, at least initially, of a sizeable quantity of solid and liquid water, fuel, oxygen and missile debris.

It is our conclusion that after the first few seconds the camera operators were tracking the cloud of solid materials and not the vapors, which were left behind after having quickly come to equilibrium with the atmospheric constituents. Indeed, the operators may not have been able to see the vapor clouds.

Spectral Characteristics of the Cloud All material in the cloud, whether solid, liquid or vapor, would scatter sunlight to some degree and hence would exhibit a solar spectrum. If this scattered light were intense enough, spectrograms could be obtained which had an intensity greater than the scattered light from the sky alone.

Other reactions could take place which could lead to a spectrum other than solar. Notably water vapor reacting with sunlight [Potter 1962] could give rise to the OH radical which in turn reacts with the ambient O atoms. This reaction could conceivably result in resonant scattering of sunlight near 3064 Å. With suitable instrumentation this radiation might conceivably be detected. The chances of observing this radiation against a daylight sky are most remote.

However, for the SA-2 release neither spectrographic equipment nor filter systems were available and hence no spectral data were obtained.

Location of Water Cloud in Space It had been hoped that the vapor cloud created by the water could be observed for a sufficiently long time to measure the wind velocity in the 105 km region. As shown by recent studies on Project Firefly [Edwards 1962], the winds in this region of the atmosphere are extremely turbulent during twilight. However, the quantity of material used in the Firefly studies is not sufficient to be seen optically during daylight. It had been hoped that the quantity of water carried by the Saturn vehicle would allow a short measurement of this elusive atmospheric parameter.

As pointed out previously the cloud was undoubtedly composed of solids and vapors. Assuming that the vapors or their reaction products could be seen, the instrumentation used to photograph the cloud did not permit the location of the cloud components in space and hence position data could not be obtained.

To locate the cloud components in space it is necessary to have either azimuth and elevation readings for the cameras or to have the cloud photographed against a star background. Neither set of data was available from the photographs. In addition, the cameras used had fields of view which were so narrow that only a portion of the cloud was visible on the photograph after the first few seconds.

Had these two limitations not existed it may have been possible to separate vapor from solids and to have obtained some idea of wind velocity and turbulence.

From previous studies on the water release at Wallops Island [Edwards 1962], the solids were found, as expected, to follow the ballistic trajectory. Although the ballistic trajectory for the SA-2 above the 105 km release point was calculated by extrapolation of missile trajectory up to the 105 km region, it was not used since az-el information was not available for the observed clouds.

Position of High Intensity Line In frames number 8 through 27 of the Patrick photographs on 35 mm film operating at 94 fps, an elongated object was observed. It is not known what this object or cloud was but it was observed to move out from the center of the cloud at a projected velocity of 0.75 km/sec and an acceleration of 1.02 km/sec^2. Figure 6 is a plot of the location as a function of time.

Cloud Growth Cloud growth during the first few seconds after release has been determined from the photographs taken at several of the observing sites. The results are presented in Figures 7 and 8. It will be noted that there is some variation in the cloud diameter as observed at the various sites. A major factor in this variation resulted from the variety of film types and focal length lenses used at the sites. Cloud size was determined by measuring the image diameter on the photograph and then determining the object (cloud) diameter from the following relationship.

$$D_o = \frac{D_i R}{f} \cos^2 (\Phi)$$

$$\Phi = \tan^{-1}\left(\frac{\sqrt{x^2 + y^2}}{f}\right)$$

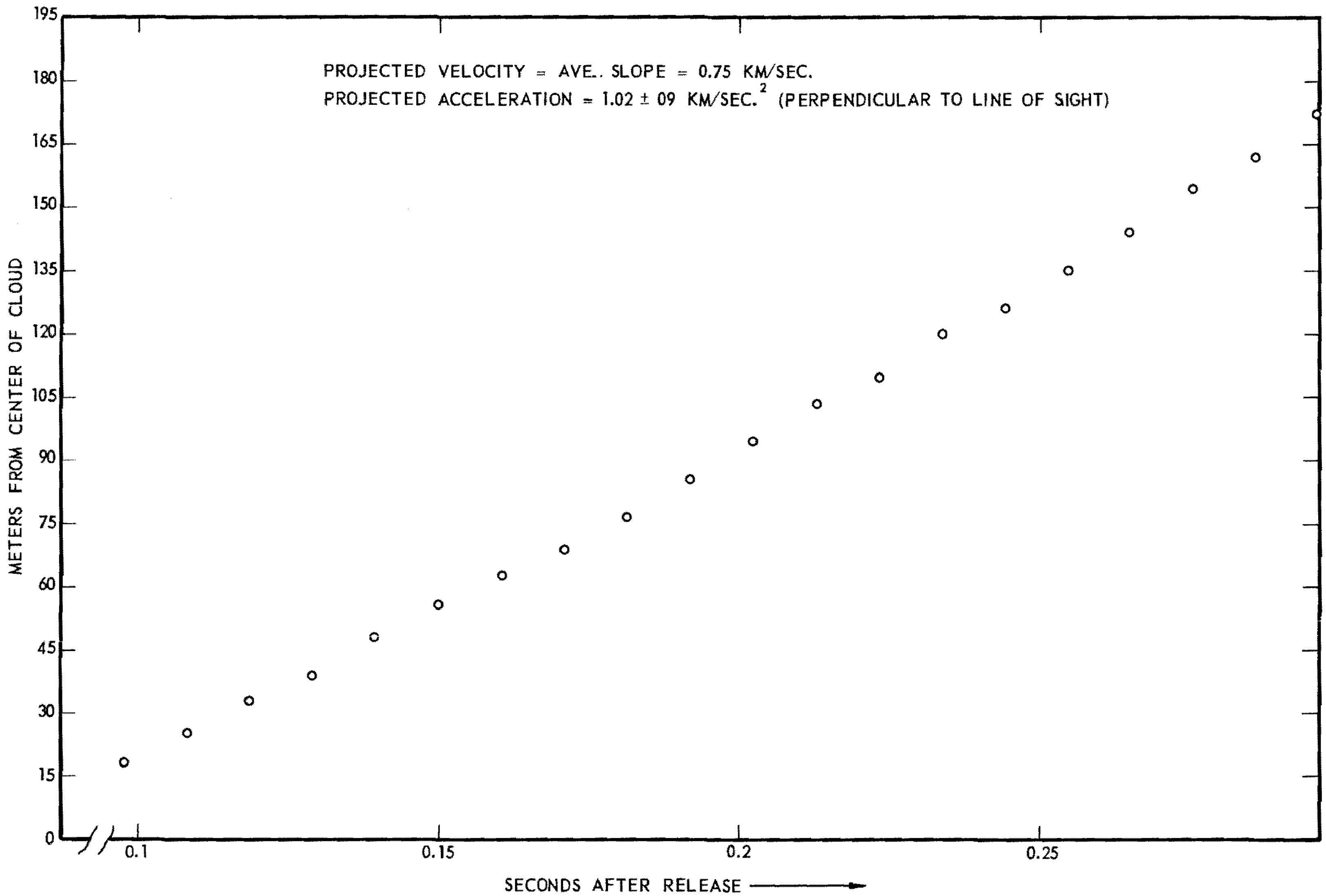

Figure 6. Apparent Position of High Intensity Line Visible in Frames Number 8 to 27 of Patrick A.F.B. Photographs 35 mm, 94 fps.

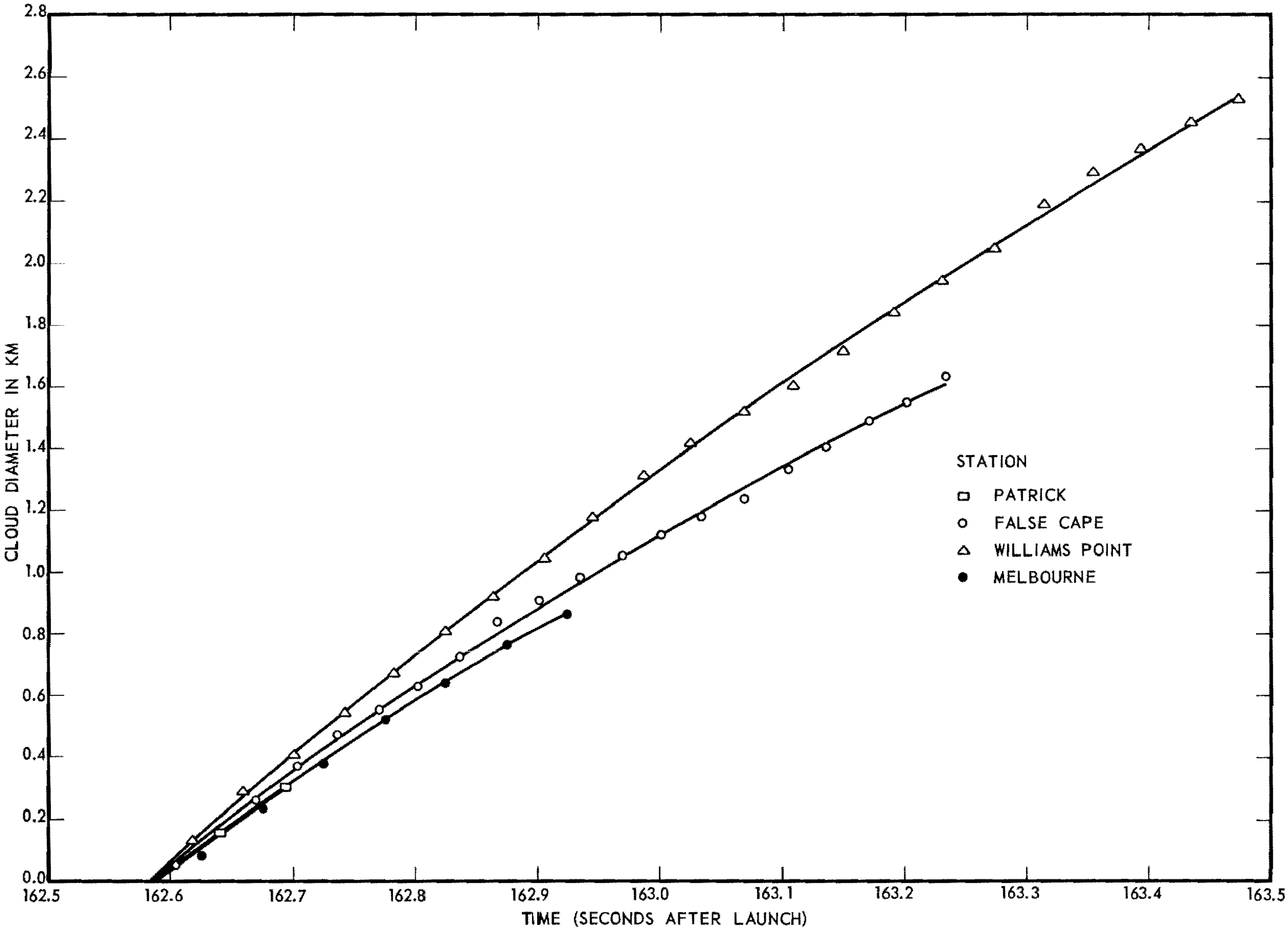

Figure 7. Diameter of Cloud Versus Time.

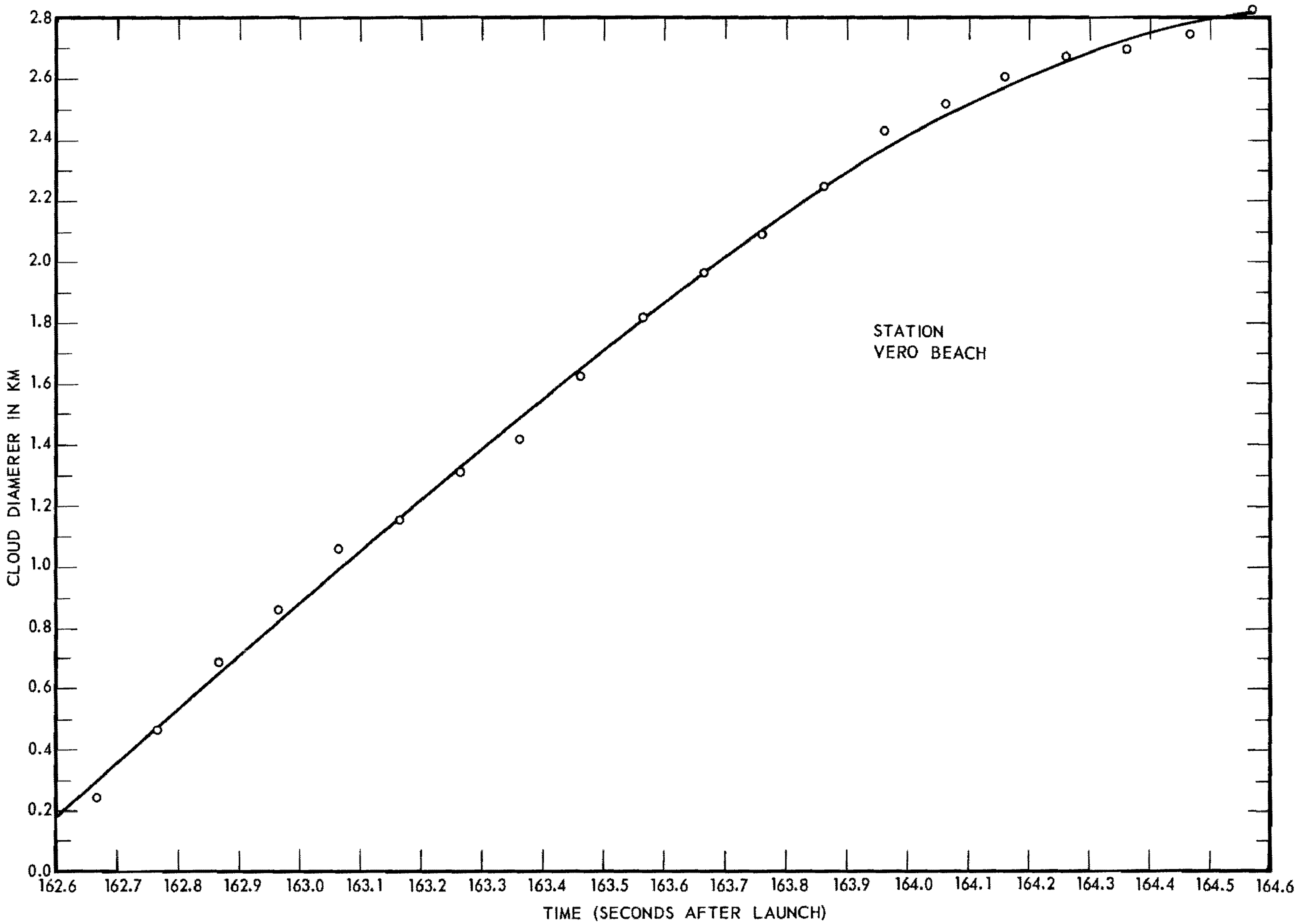

Figure 8. Diameter of Cloud Versus Time.

where

D_o = diameter of the object (cloud)

D_i = diameter of the cloud image on the film

R = slant range from film to object

f = focal length of lens

x and y are the coordinates of the center of the image from the center of the film.

In this study $\cos^2(\Phi) \approx 1$ since the cloud was kept approximately in the center of the frame by the camera operators.

In Figure 9 the average rate of change of diameter is given.

The curve drawn on each of the plots of Figures 7 and 8 is the least squares fit to the points calculated by the above equation.

The mathematical expression for each of the curves is as follows:

False Cape: $D = -2.0399 + 4.0659\,(t-162) - 0.89425\,(t-162)^2$

Patrick: $D = -3.9761 + 9.9474\,(t-162) - 5.4537\,(t-162)^2$

Melbourne: $D = -2.6214 + 5.5269\,(t-162) - 1.9024\,(t-162)^2$

Vero Beach: $D = -0.65854 + 1.1446\,(t-162) + 0.58526\,(t-162)^2 - 0.19586\,(t-162)^3$

Williams Point: $D = -2.1534 + 4.1187\,(t-162) - 0.61899\,(t-162)^2$

where t is the time in seconds from range zero.

Again, the most serious limitation in growth data resulted from the use of long focal length lenses with small fields of view.

Intensity of Cloud An attempt was made to determine the intensity of the cloud. However, several limitations precluded obtaining much meaningful data. Densitometer studies were made of the dark spot in the middle of the cloud and it was found to have the same intensity as sky background. We therefore suspect that a hole exists in the middle of the cloud. Again the small fields of view of the cameras did not record cloud images for a sufficiently long time to allow the water to come to equilibrium with the ambient. Much of the data was

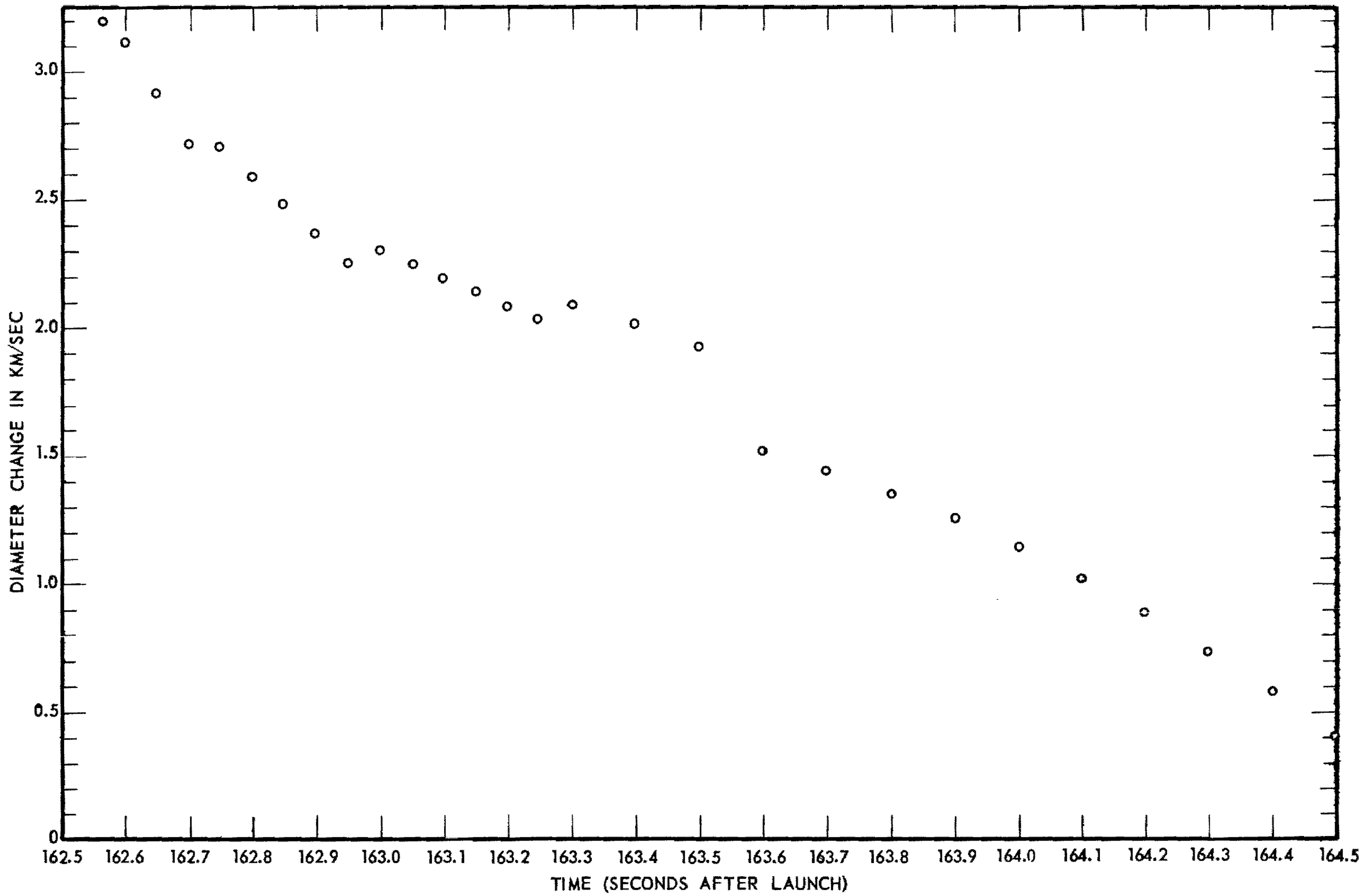

Figure 9. Average Rate of Change of Diameter Versus Time.

taken on color film, which increases the difficulty in densitometry. Also the absence of sensitometric strips being processed with the film and the resulting lack of an H-D curve further complicated intensity studies.

CONCLUSIONS

The release of water from the saturn missile was a success optically, at least in a qualitative sense, and the results have been reported very nicely in a paper prepared by scientists of the Marshall Space Flight Center. [Johnson et.al. 1962]. Hence, very little attempt has been made in this study to describe the startling features and motions which were observed.

Our analysis has centered primarily around attempts to obtain quantitative data on such parameters as atmosphere winds, turbulence, cloud spectral characteristics, cloud growth, and intensity. For various reasons, which are listed in detail in the Recommendations section, quantitative data have been very sparse.

Our studies have shown missile orientation and behavior immediately after the water release. Cloud growth during the first few seconds after release has also been given as well as several calculations to show the quantity of material (fuel, LOX, water) that could be expected to attain the vapor state.

Generally speaking, our greatest contribution will probably come from pointing out many of the instrumentation limitations which were evident from the photographs taken of the water cloud.

RECOMMENDATIONS

Since the equipment used to obtain photographs was primarily intended for tracking missiles which are small, fast-moving objects, it is not surprising that several serious limitations developed when these same cameras were used to track a very large, slow-moving object such as the water cloud. Everything considered, I think all concerned are to be congratulated for the excellent photographic records which were obtained and at a very minimum cost.

Several specific recommendations will be made realizing that many may be incompatible with the primary mission - namely test of the Saturn booster.

(1) Cloud composition is complicated by the fact that liquid oxygen, fuel, and water are all released at the same time. If the water could be released at a time either before or after the LOX and fuel, the analysis problem would be simplified.

(2) Spectral characteristics of the cloud are badly needed. A slitless spectrograph with continously moving film would possibly give results. If spectrographs cannot be obtained, a suitable choice of narrow band filters, including polarizers for particle size studies, could possibly differentiate between the background composed of the solar spectrum and the water cloud and its reaction components.

(3) To determine cloud location in space, highly accurate azimuth and elevation setting for cameras from at least two stations are needed. Ideally, photographs from three or four stations should be taken with accurate azimuth-elevation readings given to correspond to each photographic frame.

For example, an error of $\pm 1^{\circ}$ in azimuth or elevation will give approximately $\pm$ 3 km error in altitude for a cloud at 100 km altitude. An alternative method would be to take a series of photographs of the cloud at a single az-el setting with a wide field of view camera and then without changing the az-el setting obtain several photographs of the star background at a known time on either the night preceding the missile launch or the night following. Camera orientation (direction of vertical) should be noted as well as camera tilt. This latter is not necessary if a star background is obtained since a computer program is available to calculate camera tilt as well as focal length.

(4) One of the most serious limitations of the equipment used was the long focal length of the lenses and resultant small field of view. The water

cloud rapidly expanded to more than fill the field of view and hence the major portion of the cloud was not photographed. Short focal length lenses and a field of view of 20° to 30° in both horizontal and vertical directions are highly recommended.

(5) Cloud growth studies were primarily limited by small field of view cameras and insufficient use of black and white film.

(6) Intensity studies were limited by too little use of black and white film compared to color and the lack of sensitometric data and H and D curves from the film processing.

In summary the following recommendations are made for consideration on future releases.

(1) Shorter focal length lenses should be used to achieve a field of view of 20° to 30° in both horizontal and vertical directions.

(2) Azimuth-elevation or star background data should be provided for each frame of film. The exact time of star calibration should be recorded.

(3) Spectral data should be obtained by spectrographs or filters.

(4) Black and white film should be used instead of color.

(5) Sensitometric strips should be processed with the film and H-D curves established.

(6) Separate destruct systems should be provided for the water and fuel-LOX so the water is not released at the same time as other constituents.

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